Fuel Cell Catalyst

Fuel Cell Catalyst is a quarterly newsletter linking government and industry fuel cell activities.

Vol. 1, No. 1 • Fall 2000

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Fuel Cell Catalyst is a quarterly publication by the U.S. Fuel Cell Council, National Energy Technology Laboratory, and National Fuel Cell Research Center.

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Delphi Automotive/BMW SOFC APU Prototype

Solid Oxide Fuel Cell

Emergence of a Technology

Within the current framework of increased demand for high quality and reliable energy combined with increasing expectations for environmental sensitivity, the solid oxide fuel cell (SOFC) is emerging as a potential breakthrough technology for the low cost production of electricity from currently available fossil fuels.

An SOFC is a *solid state* fuel cell constructed of ceramic materials (metal oxides) and metals. SOFCs share the solid state electrolyte feature with only one other fuel cell type, the proton exchange membrane fuel cell (PEMFC). Solid state construction offers increased reliability and durability with less corrosion and no need to manage electrolyte evaporation or circulation.

The SOFC concept involves conduction of oxygen ions ($O^{=}$) within the electrolyte at high temperatures (650-1000^{o}C) making it inherently more fuel flexible than other fuel cell types. This differs from lower temperature fuel cell types that typically conduct hydrogen ions, or protons (H^{+}), through the electrolyte. Whereas most other fuel cells are susceptible to carbon monoxide (CO) poisoning, SOFCs can use CO as a fuel to produce electricity, oxidizing CO to carbon dioxide in the anode compartment. To date, SOFCs have been operated on hydrogen, carbon monoxide, natural gas, propane, landfill gas, diesel and JP-8.

SOFC systems are being advanced by a number of companies and organizations with three major fuel cell stack designs emerging. The major design types are tubular, planar, and monolithic.

Tubular SOFC designs are closer to commercialization and are being produced by Siemens Westinghouse Power Corporation (SWPC), one Australian and one Japanese company. The tubular SOFC design constructs the stack as a bundle of tubular electrode–electrolyte assemblies. Air is typically introduced to the inside of each tube while fuel bathes the outside of the tubes to produce electricity. Demonstrations of tubular SOFC technology have produced as much as 220 kW.

The planar and monolithic designs have been demonstrated in single cell and smaller stack sizes in the single to multiple kilowatt range. Compared to tubular designs, planar SOFC designs are simpler to manufacture and consist of flat plates bonded together to form the electrode-electrolyte assemblies. Monolithic SOFC design consists of alternating anode and cathode compartments within a single layer of manufactured ceramic material. The alternating compartments are divided by individual electrode-electrolyte assemblies. Companies developing these designs in the U.S. include McDermott Technology, Inc., Ceramatec, Inc., Honeywell, Technology Management, Inc., SOFCo, and Ztek, Inc. In addition, there are at least seven companies in Japan, eight in Europe, and two in Australia developing SOFC technology.

The high temperature operation of an SOFC has advantages and disadvantages. The advantages include the use of high temperature heat to reform hydrocarbon fuels to hydrogen(H_2)/carbon monoxide(CO) mixtures for direct use in the fuel cell. This reformation process requires heat to proceed. The high temperature heat also allows significant co-generation and/or integration with a heat engine cycle. The disadvantages of high temperature operation include the need to insulate the technology to protect from injury and the requirement of more costly materials of construction. SOFCs

"The hybrid SOFC cycle . . . offers the potential of fuel-to-electricity efficiencies in the 75-80% range."

SECA Solicitation

In June 2000, a Solid-State Energy Conversion Alliance workshop gathered input from 180 attendees representing industry, universities, national laboratories, the Department of Defense and other organizations to help formulate a solicitation to select several Industry Integration Teams to develop SECA fuel cell systems. Using this input, SECA issued a "Draft Program Solicitation" in September for development of a total of three solid oxide fuel cell systems (3kW-10kW). Comments on the draft were due on October 11, 2000.

According to the draft solicitation, the anticipated Government funding per team per year is approximately $5 million, and the number of teams will be determined at the discretion of the Government. The draft noted that funds are not currently available for this solicitation, and the Government's obligation under any cooperative agreement awarded is contingent upon the availability of appropriated FY2001 funds. SECA expects to issue a final solicitation in early November 2000. The solicitation comprises 60 percent of the expected SECA budget.

The remaining 40% of SECA's budget is reserved for the Core Technology Program, which addresses crosscutting technical issues in solid-state fuel cell systems. A solicitation will be issued for the Core Technology Program in Spring 2001, with topics based on Industry Integration Team needs. The selection criteria for the Core Technology Program solicitation will be more heavily weighted toward technical considerations.

The teams will have available to them common technologies, design elements, and materials essential to achieving breakthrough performance.

have higher overall fuel-to-electricity efficiency than lower temperature fuel cells (e.g., PEMFC) operated on available hydrocarbon fuels (e.g., natural gas). When integrated with a heat engine cycle, efficiency can be increased even further. The hybrid SOFC cycle, which integrates an SOFC into a gas turbine cycle, offers the potential of fuel-to-electricity efficiencies in the 75-80% range. This remarkably high efficiency is unmatched by any other technology. Although in the early stages of development, hybrid designs and systems are now emerging with the first demonstration being accomplished by Southern California Edison and Siemens Westinghouse Power Corporation at the National Fuel Cell Research Center.

SOFC systems have been operated all over the world, proving SOFC performance and features. Examples include the tubular SOFC design of Siemens Westinghouse Power Corporation that has demonstrated over 100,000 hours of operation with very little cell degradation, and the SOFCo planar SOFC design exhibiting power densities up to 1000W/l.

The high efficiency, low emissions, and fuel flexibility features of SOFCs together with recent demonstrations of robust and reliable operation and high power density, make SOFCs a key emerging technology (prime candidate) for meeting future energy demands.

JACOB BROUWER, PH.D., ASSOCIATE DIRECTOR, NATIONAL FUEL CELL RESEARCH CENTER

Alliance to Spur SOFC Development

Recent advances in the development of solid oxide fuel cells may make the technology a tough competitor in mobile, portable and stationary power applications. To spur even faster development of SOFCs for commercialization in these applications, a new alliance - linking government, industry, universities and national laboratories - has been formed that may prove to be a model for future government-industry collaborations.

The recently launched Solid-State Energy Conversion Alliance (SECA) has set a 2010 SOFC system cost goal of $400/kW, and aims to develop 5kW-sized "core modules" that can be interconnected to meet a variety of power demands for residential, mobile, or military applications. The modules would measure 4 by 4 by 12 inches, weigh less than 50 kilograms, and have a surface temperature less than 45 degrees C.

The National Energy Technology Laboratory (NETL) and Pacific Northwest National Laboratory (PNNL) - the driving forces behind SECA - say this collaboration represents a new model for joining government and private industry technology development. SECA will be structured into industrial development teams, and a core or cross-cutting technology program. A government-led project management team will coordinate both activities.

The "Industry Integration Teams" will be selected on the basis of a program solicitation (see sidebar) inviting teams to participate in a collaborative, co-funded effort to develop fuel cells and the industry infrastructure required to produce them at competitive cost. Each team is responsible for meeting the market requirements for its targeted customers. The teams will have available to them common technologies, design elements, and materials essential to achieving breakthrough performance.

The "Core Technology Program" (CTP) consists of universities, national laboratories, and other research-oriented organizations. Their projects address crosscutting technical issues in solid-state fuel cell systems. There is a "circular" relationship between the Industry Integration Teams and the CTP. The Industry Integration Teams communicate their technology development needs to the project managers. The project managers translate these needs into research topics for the CTP. Some of the primary topics that will likely be the focus of the CTP are Fuel Processing, Manufacturing, Controls & Diagnostics, Power Electronics, Modeling & Simulation, and Materials. Participants in the CTP develop solutions that are transferred back to the Industry Integration Teams.

SECA's treatment of intellectual property is the cornerstone of the alliance, and is a pilot program that DOE hopes will become the model for other technology development programs. DOE anticipates that all members of SECA will be granted rights to own any inventions they make under the program. The intellectual property (IP) rights of the Industry Integration Teams are complete. However, those of the CTP are slightly limited. Participants in the CTP must be willing to license their patented technologies to any of the Industry Integration Teams, within reasonable time limits and other constraints.

DOE cites the advantages of this type of approach:

- Technologies developed in the CTP can be incorporated into any designs that will benefit from them - not just into the designs of the highest bidder;
- Research performers in the CTP will have a ready market for their inventions and will reap royalties if their invention is used in a commercialized fuel cell system;
- Value of a technology is increased - if a technology is important, all of the Industrial Integration Teams will need it to remain competitive.

DOE believes the Industry Integration Teams will be more likely to identify research needs if they are assured that all solutions will be within reach, and that this intellectual property approach will open the doors to collaboration.

Program solicitations for the Core Technology Program will be issued in Spring 2001. In the meantime, the Industry Integration Teams - which will be chosen from a Fall 2000 solicitation - will discuss and assemble a list of research needs, based on their respective approach to clearing the hurdles that stand between SOFC state-of-the-art, and future commercialization as a clean, efficient, and cost-competitive power source.

BY BERNADETTE GEYER

SOFC State-of-the Art
McDermott International

Because of their thermal characteristics and fuel tolerance, solid oxide fuel cells (SOFCs) are well suited to a variety of stationary, mobile/portable, and military applications. SOFCo - a part of McDermott International, Inc. - has developed a unique SOFC architecture and manufacturing technology which combines the materials of SOFCs with the low cost manufacturing techniques of multi-layer ceramic (MLC) electronic packaging to produce high performance, low cost fuel cell stacks.

SOFCo itself will target stationary power applications with high quality, high reliability, premium power requirements. The initial product offering, scheduled for commercialization by 2005, will be a 250kW cogeneration capable unit with integrated reforming, fueled by natural gas.

The modular nature of the SOFCo fuel cell stack design will allow sizing of stationary power products over a broad range from 2kW up. As the markets for fuel cell applications evolve, the SOFCo architecture will allow rapid adaptation to market size requirements.

In addition to providing integrated systems for stationary power applications applications, SOFCo also expects to provide stacks for a wide range of mobile, marine and military applications. SOFCo is currently in discussions with several potential system integrators who hold leading positions in their served markets. SOFCo plans to work with these packagers to provide the market standard for SOFC systems with SOFCo inside.

McDermott International, Inc., is a leading worldwide energy services company. The company's subsidiaries manufacture steam-generating equipment, environmental equipment, and products for the U.S. government. They also provide engineering and construction services for industrial, utility, and hydrocarbon processing facilities, and to the offshore oil and natural gas industry.

WILLIAM P. SCHWEIZER, MANAGER SOFC DEVELOPMENT, MCDERMOTT INTERNATIONAL

photo above left: Fuel cell stack testing is a critical component of SOFCo's development program.

photo above right: 100 kW SOFC cogeneration operating system in the Netherlands

SOFC State-of-the Art
Siemens Westinghouse Technology

The state-of-the-art in SOFC technology by Siemens Westinghouse Power Corporation is embodied in the tubular cell for distributed generation applications developed under a cooperative agreement with DOE through the National Energy Technology Laboratory (NETL). Great progress has been made by Siemens Westinghouse in recent years, as exemplified by the two major proof-of-concept demonstrations SWPC currently has in the field: a 100 kW cogeneration system in the Netherlands operating at >46% electrical efficiency, and a 220 kW SOFC/gas turbine hybrid that was installed in May 2000 in California and achieved 52% electrical efficiency.

The system in the Netherlands, supplied to EDB/Elsam, a group of Dutch and Danish energy companies, has been producing grid power and hot water for district heat for nearly 2 years. It holds the record for the longest running high temperature fuel cell system, with >15,000 hours on the complete system and >11,000 hours on the cell module.

Its record breaking performance, coupled with the highest efficiency of any fuel cell currently operating on natural gas, has led Siemens Westinghouse to plan a series of commercial prototypes for future cogeneration products based on its design. The first of these prototypes, a 250 kW cogeneration system, will begin operation for Kinetrics formerly Ontario Power Technologies of Toronto in mid-2001.

The California system, owned by Southern California Edison, uses a cell module of the same size and design as the Netherlands system, but pressurizes it and integrates it with a microturbine generator to produce the first ever fuel cell/gas turbine hybrid.

During its initial operating period the hybrid system achieved 52% electrical efficiency, setting a new record for a fuel cell system operating on natural gas. The unit is undergoing modifications prior to extended testing and will return to operation in December 2000. Prototype hybrid systems of 300 kW and 1 MW, capable of 60% electrical efficiency, are under contract and planned for 2002 and 2003.

Siemens Westinghouse is also examining SOFC configurations for broader market sectors, including small systems that could find uses in a variety of high volume applications.

CHRIS FORBES, MANAGER SOFC BUSINESS DEVELOPMENT, SIEMENS WESTINGHOUSE POWER CORPORATION

Calendar

POWER-GEN International

Orlando, Florida, USA - 14-16 November 2000.
See www.powergen.com for more information.

International Symposium on Fuel Cells for Vehicles

Nagoya, JAPAN - 20-22 - November 2000. For more information, email takeda@chem.mie-u.ac.jp.

Electric Power 2001

Baltimore, Maryland, USA - 20-22 March 2001.
Email Craig Moritz at craigm@tradefairgroup.com for more information.

Hannover Fair 2001:

The world fair for Energy Management and Technology
GERMANY - 23-28 April 2001. See www.h2fair.de/e/hm01/index.html for more information.

Seventh International Symposium on Solid Oxide Fuel Cells

Tsukuba, Ibaraki, Japan - 3-8 June 2001.
Email sofc7@nimc.go.jp for more information.

industrynotes

In cooperation with BMW and Renault, Delphi Automotive Systems is developing a solid oxide fuel cell system to be used as an auxiliary power unit. In 1999, Delphi successfully tested a solid oxide fuel cell system – integrating a Delphi fuel reformer with a Global Thermoelectric fuel cell stack – that can run on gasoline or diesel. The companies expect a mid-decade launch of the technology on commercial vehicles.

Canada's Global Thermoelectric successfully tested its next generation residential solid oxide fuel cell system. The output of the new scalable system is 1.35kW. The company achieved significant improvements in power output from its solid oxide fuel cells, increasing power output by 60% at an operating temperature of 800°C.

Ceramic Fuel Cells Limited (CFCL), an Australian fuel cell company, has completed its first large-scale experiment in the development of its flat-plate solid oxide fuel cell technology. A complete 25kW system was built, including a large fuel cell stack, balance-of-plant and control system. The experiment supplied important data on the operation of larger stacks and system-stack integration, which will be useful for the next phase – a major product development program.

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